METHOD FOR SETTING THE SWITCHING TIMES, IN PARTICULAR

DEAD TIMES, IN AN INVERTER AS A FUNCTION OF THE

ENERGY DETECTED, AS WELL AS INVERTER

The invention relates to a method for an inverter,
in particular for a solar inverter, for feeding energy
produced by a d.c. voltage source into an a.c. voltage
grid, in which the produced energy of the d.c. voltage
source is chopped in the form of a pulse width modula-
tion by a bridge inverter, by alternate switching of
switching elements connected in parallel and connected
in series, and this chopped energy is transmitted via a
transformer which is connected between the switching
elements that are connected in series, whereupon the
energy transmitted is rectified again and fed into the
a.c. voltage grid via a buck chopper, wherein, for a
power adaptation, the switching times of the switching
elements of the bridge inverter are controlled, or
regulated, respectively.

Furthermore, the invention relates to an inverter,
in particular to a solar inverter, for feeding energy
produced by a d.c. voltage source into an a.c. voltage
grid, comprising a bridge inverter, a transformer, a
rectifier, a back chopper including a full bridge and

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an output filter, a control device being provided for controlling the parameters of the inverter.

In the inverters, in particular solar inverters, known from the prior art, the assembly preferably consists of a bridge inverter, a transformer , a rectifier, a buck chopper including a full bridge and an output filter. A d.c. voltage source, in particular a solar module, is connected to the inverter, whereas the output of the inverter is connected to an a.c. voltage grid for feeding in energy. The energy produced by the d.c. voltage source is chopped by the bridge inverter in the form of a pulse width modulation, by alternating switching of switching elements connected in parallel and connected in series, and this chopped energy is transmitted via the transformer which is connected between the switching elements that are connected in series, whereupon the energy transmitted is rectified again and is fed into the a.c. voltage grid via a buck chopper.

JP 08-228488 A, JP 09-047082 A as well as EP 0 871 285 A1 describe devices and methods for setting the dead times of inverters as a function of an output parameter.

With the solar inverters known from the prior art

it is disadvantageous that a power adaptation of the inverter is possible only via the pulse width modulation of the bridge inverter, whereby it is not always ensured that the latter is operated at an optimum. If, for instance, less energy is delivered by the d.c. voltage source, it may happen that the pulse width is reduced to an extent that a further control or regulation via the pulse width is no longer possible. In case of an excessively high energy supply via the d.c. voltage source this may also happen, since in this case the pulse width is adjusted to the maximum so that, again, further control or regulation will no longer be possible.

Therefore, the object of the present invention consists in providing a method for an inverter for feeding an energy produced by a d.c. voltage source into an a.c. voltage grid, and of an inverter, with the degree of effectiveness being substantially increased in a simple form.

With regard to the method, the object according to the invention is achieved in that the energy produced by the d.c. voltage source is detected in particular at cyclical intervals or permanently, and in that the switching times of the switching elements of the bridge

inverter are set as a function of the detected energy of the d.c. voltage source.

Thus, an adaptation of the inverter to the input power delivered is possible in a simple form. It is thereby ensured that the inverter can always be optimally regulated, whereby the degree of effectiveness is substantially increased. By adapting the switching times of the switching elements it is ensured that the parasitic capacities stored in the switching elements of the bridge inverter can be completely recharged and no excessively long switching pauses can occur at the same time. By changing the frequency of the switching times, it is achieved that the switching losses will be reduced proportionally, and thus, the degree of effectiveness of the circuit will be substantially improved.

Here, the dead time of the switching elements for switching over from one switching element to a further switching element, connected in series, of the bridge inverter can be set as a function of the energy detected.

As an alternative or in addition to the dead time, also the period duration, or frequency, respectively, for the pulse width modulation for switching over from one switching element to a further switching element,

connected in series, of the bridge inverter can be set as a function of the energy detected.

Advantageously, the switching times of the switching elements of the bridge inverter are evaluated as a function of the energy detected and are set automatically.

According to a further feature of the invention, the switching times of the switching elements of the bridge inverter are calculated as a function of the energy detected, or are chosen from a table comprising respective deposited data, in which table, for instance, for various mean values respective values have been deposited for the switching times, in particular for the dead time and/or for the pulse duration, or the frequency, respectively.

Moreover, the switching times of the switching elements of the bridge inverter can be set as a function of the mean value of the current flowing over the primary winding of the transformer. Measurement of the mean value of the current flowing over the primary winding of the transformer is one possible way of detecting the energy of the d.c. voltage source.

Advantageously, the switching elements are activated at appropriately fixed points of time.

Moreover, the object of the invention is also achieved by an above-mentioned inverter, in particular by a solar inverter, wherein a device for detecting the energy produced by the d.c. voltage source is provided, which device is connected to the control device, and wherein the bridge inverter is designed for adapting the switching time, in particular the dead time for switching over of the switching elements and/or a pulse duration, or frequency, respectively, for the pulse width modulation as a function of the energy detected.

The device for detecting the energy produced by the d.c. voltage source, in particular by the solar module, may be a current measurement device at the primary side of the transformer.

Even though the present description is mainly directed to solar inverters, the present invention may also be utilized in other inverters.

The present invention will be explained in more detail by way of the accompanying drawings which illustrate exemplary embodiments for the method and for the solar inverter.

Therein,

Fig. 1 shows a block diagram of a solar system comprising a solar inverter for feeding into an a.c.

voltage grid, in a simplified, schematic representation;

Fig. 2 shows a diagram of the switching sequence of a bridge inverter of the solar inverter in a simplified, schematic representation; and

Fig. 3 shows a further diagram of the control sequence in a simplified, schematic representation.

In Fig. 1, a schematic circuit diagram of a solar inverter 1 for feeding energy produced by a d.c. voltage source 2 into an a.c. voltage grid 3 is shown. Additional protection devices, e.g. to protect against overload, short circuit etc., have not been illustrated in the diagram to provide for a better overview.

The d.c. voltage source 2 is formed by a solar module 4, e.g., for the production of energy by solar radiation. It is also possible to provide a fuel cell, e.g., instead of the solar module 4 or in addition thereto. The solar module 4 is connected to a solar inverter 1. The solar inverter 1 consists of a bridge inverter 5 at which several switching elements 6 to 9, such as, e.g., thyristors, transistors or the like, are arranged in bridge circuit so that always two switching elements 6, 8 and 7, 9 are connected in series. The full bridge is formed by two half-bridges connected in

parallel with each other. Instead of the full bridge shown, it is, of course, also possible to use only one half-bridge, i.e. two switching elements 6 and 8 or 7 and 9. In parallel with each switching element 6 to 9, one diode 10 to 13 each and, as schematically illustrated, one parasitic capacity 14 to 17 each are arranged. Of course, in parallel with the diodes 10 to 13, or the connecting elements 6 to 9, respectively, additional capacitors 14 to 17 can be connected in parallel with the parasitic capacities.

Furthermore, the solar inverter 1 includes a transformer 18 in which the primary side, i.e. the primary winding 19, is connected between the two switching elements 6, 8 and 7, 9 which are connected in series, i.e. at the center of the switching elements 6 to 9. On the secondary side of the transformer 18, i.e. at the secondary winding 20, a rectifier 21, a smoothing filter choke with intermediate circuit capacitor, a buck chopper 22 with a full bridge connected thereto, as well as an output filter 23 are connected, from which output filter 23 feeding into the a.c. voltage grid 3 is effected.

Moreover, the solar inverter 1 has a control device 24 by means of which controlling of the individual

circuit components or circuit groups of the solar in-
verter 1 is effected. For this purpose, schematic con-
trol lines 25 to the individual switching elements 6 to
9 have been entered in the drawing. In order to be able
to determine the energy produced, a current measurement
unit 26 is arranged at the primary side of the trans-
former 18, which measurement unit is formed by a shunt
resistor. The current measurement unit 26 is connected
to the control device 24 via measurement lines 27.
Thus, the current, or voltage, respectively, flowing
over the current measurement unit 26 or the energy can
be detected by the control device 24.

The functions of the individual circuit members or
circuit groups, respectively, of the solar inverter 1,
are not further described, as they are already suffi-
ciently known from the prior art. It is only mentioned
briefly that the energy produced by the d.c. voltage
source 2 is chopped by the bridge inverter 5 by alter-
nate switching of the switching elements 6 to 9, con-
nected in parallel and connected in series, of the full
bridge, and transmitted via the transformer 18. The en-
ergy transmitted by the transformer 18 in turn is rec-
tified by the rectifier 21 and finally fed into the
a.c. voltage grid 3 via the buck chopper 22 and the

full bridge following thereafter and the output filter 23. By modulating the pulse width, the energy transmitted can be changed.

Figs. 2 and 3 now illustrate a novel activation of the bridge inverter 5. For this purpose, in the diagrams 28 to 33 simplified, optimized signal courses of the control signals for activating the switching elements 6 to 9 of the bridge circuit, the voltage U_{tr} at the transformer 18 as well as the current I_{tr} through the current measurement unit 26 as a function of time are illustrated.

In known solar inverters 1, particularly in the bridge inverters 5 arranged therein on the primary side of the transformer 18, activation and switching over is effected by a fixed defined frequency as well as by a fixed defined switching time, or a switching sequence, respectively, particularly a fixed defined dead time. In known systems, a power adaptation, or power change, respectively, of the solar inverter 1 is effected via pulse width modulation, wherein, depending on the amount of energy delivered, the pulse width, i.e. the switched-on duration of the switching elements 6 to 9 of the bridge inverter 5 is changed.

As can be seen from Fig. 2, the course of a pulse

width modulated bridge inverter 5 is such that always
two switching elements 6, 9 and 7, 8 are alternately
activated. This is visible in the diagrams by corre-
sponding activation pulses 34 to 37 for the switching
elements 6 to 9, which pulses are emitted from the con-
trol device 24. Energy will flow over the primary
winding 19 of the transformer 18 if the switching ele-
ments 6 and 9 as well as 7 and 8 are simultaneously
connected through. In the illustrations, this corre-
sponds to those times during which the control pulses
34 and 37 of the switching elements 6 and 9 as well as
35 and 36 of the switching elements 7 and 8 overlap
each other. During these overlapping switching times
38, thus an energy transmission occurs via the trans-
former 18, as schematically illustrated by the voltage
pulses 39 in the diagram of the temporal course of the
transformer voltage U_{tr}.

If, e.g., the switching elements 6 and 9 are acti-
vated at the same time, energy can be transmitted via
the transformer 18 during the switching time 38, start-
ing from a point of time 40. An activation of the
switching elements 7 and 8 causes an energy transmis-
sion with a reversal of the polarity of the voltage at
the transformer 18. The switching-over procedure is

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such that, e.g., at point of time 41, the switching
element 9 is deactivated, and after a so-called dead
time 42 has passed, the switching element 8 is acti-
vated at point of time 43. Subsequently, at point of
time 44, the switching element 6 is deactivated, and
the switching element 7 is activated again by the con-
trol device 24 at point of time 45, after a dead time
42 has passed. Thus, switching over from the switching
elements 6 and 9 to the switching elements 7 and 8 has
been carried out. Consequently, a flow of current can
occur over the primary winding 19 of the transformer 18
in the opposite direction, as illustrated by a now
negative voltage pulse 46, so that further energy
transmission will occur to the secondary side of the
transformer 18. In order to switch over again to the
switching elements 6 and 9, the switching element 8 is
deactivated at point of time 47, and the switching ele-
ment 9 is activated at point of time 48, after the dead
time 42 has passed, whereupon the switching element 7
is deactivated at point of time 49, and the switching
element 6 is activated at point of time 50, after the
dead time 42 has passed. This alternating, cross-wise
switching of the switching elements 6 to 9 of the
bridge circuit is repeated periodically so that a cor-

responding energy transmission can occur. The switch-on

duration of the individual switching elements 6 to 9 is

controlled by the pulse width, resulting in correspond-

ingly longer or shorter voltage pulses 39 and 46 at the

transformer 18 for the energy transmission, whereby a

corresponding power change can be accomplished. Activa-

tion of the switching elements 6 to 9 by the control

device 24 preferably is always carried out at appropri-

ately fixed points of time.

It is, of course, also possible to effect the

switch-over procedure from one pair of switching ele-

ments 6 and 9 to the other pair of switching elements 7

and 8, in a different sequence. Starting out from acti-

vated switching elements 6, 9, e.g., at first switching

element 6 may be deactivated and subsequently switching

element 7 may be activated, and thereafter switching

element 9 may be deactivated and switching element 8

may be activated. Subsequently, switching element 7 is

deactivated again and switching element 6 is activated,

whereupon switching element 8 is deactivated and

switching element 9 is activated. Switching over, or

activation, respectively, of the individual switching

elements 6 to 9 again is effected after passage of the

dead time 42, as described before. What is essential is

that always an alternating, cross-wise switching of the
switching elements 6 to 9 is carried out, and that dur-
ing the switching-over procedure, always two switching
elements 6 to 9 lying at the same potential are simul-
taneously activated for a short time.

By this, it is achieved that the inductively
stored energy in transformer 18 re-charges the capaci-
tors 14 to 17 until a voltage-free switching over of
the switching elements 6 to 9 is feasible.

In order for said recharging to be possible, the
dead times 42 are provided between the deactivation and
the activation of the switching elements 6 to 9, in
which dead times a re-charging of the energy may occur.
If switching over occurs too early so that not the en-
tire energy stored has been recharged, this energy will
be destroyed when switching on, or activating, respec-
tively, the next switching element 6 to 9, leading to
high switching losses, said switching losses increasing
proportionally to the square of the voltage when
switching off, or switching on, respectively, under en-
ergy flow. If, on the other hand, switching over, i.e.
the dead time 42, is chosen to be too long, the entire
energy stored will be re-charged, yet the solar in-
verter 1 will not be operated at its optimum, since due

to the long switching times, pauses will form during
the energy transmission and, by this, the voltage-time-
window for energy transmission is reduced.

According to the invention, the control of the so-
lar inverter 1, in particular of the bridge inverter 5,
is such that a switching over adapted to the energy of
the d.c. voltage source 2, in particular of the solar
module 4, is effected by adapting the dead time 42. De-
pending on the energy supplied by the d.c. voltage
source 2, the dead time 42 for switching on and off the
switching elements 6 to 9 is defined accordingly, so
that always the entire energy of the parasitic and ex-
ternal capacities 14 to 17 can be recharged, while,
however, at the same time no overly long switching
pauses can form for the energy transmission via the
transformer 18. For, if less energy is delivered by the
d.c. voltage source 2, more time (dead time 42) will be
required so as to recharge the parasitic and external
capacitors 14 to 17 than is the case when much energy
is delivered by the d.c. voltage source 2.

For this purpose, a detection of the energy deliv-
ered by the d.c. voltage source 2 is necessary, as is
effected by a current measurement unit 26, e.g. By
this, an appropriate evaluation of the energy supplied

is enabled by the control device 24 of the solar in-
verter 1 and, thus, an automatic fixing of the switch-
ing times, in particular of the dead time 42, is car-
ried out. Evaluation and fixing of the points of time
of switching may be effected in the most varying ways.

The dead time 42 may, e.g., be determined as a
function of the mean value of the current I_{tr} through
the primary winding 19 of the transformer. This is done
such that at certain points of time, e.g. after a pre-
settable period of time has passed, the control device
24 detects the values delivered by the current measure-
ment unit 26 and forms a mean value therefrom. If this
mean value has changed compared to a previously deter-
mined mean value, a new dead time 42 is fixed. Thus, a
new dead time 42 will not be fixed after each switch-
ing-over period, but only after several switching-over
periods. The dead time 42 may be determined by a calcu-
lation or by appropriately stored data, i.e. by a table
in which, e.g., dead times 42 corresponding to the most
varying mean values are stored.

It is, however, also possible to continuously
monitor the flow of energy and for the control device
24 to react to a change of the energy flow, thereby
fixing a new dead time 42. Such an example is illus-

trated in Fig. 2, in which a change in the dead time 42
is carried out immediately in the subsequent switching-
over period, when the energy flow has changed. This can
be seen from the diagrams belonging to the points of
time 51, 52. There, the mean energy flow over the pri-
mary winding 19 of the transformer 18 at point of time
51 increases, whereupon the control device 24 will rec-
ognize that now more energy is delivered by the d.c.
voltage source 2 and, thus, more energy is stored in
the parasitic capacity. Subsequently, the control de-
vice 24 will fix a new dead time 42 which now is
shorter in comparison with the previous dead time 42,
which new dead time will be applied in the next switch-
ing-over period, as visible starting from the point of
time 53. In the exemplary embodiment illustrated, the
change of the dead time 42 will always be carried out
after a switching-over period, i.e. after a switching-
over of all the switching elements 6 to 9 has been car-
ried out once. It is, however, also possible to carry
out an adaptation of the dead time 42 with the next
switching procedure, immediately after having recog-
nized an energy flow change. At point of time 52, the
energy flow decreases again, so that a new adaptation
of the dead time 42 will be effected, since now less

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energy is stored again in the parasitic inductivity. This new dead time 42 is used by the control device 24 after having concluded the last switching-over period, as is visible at point of time 54. Since there will be a reduced current flow again starting from point of time 52, the dead time 42 will be increased as compared to the previous dead time 42 so as to allow for a complete re-charging of the energy stored in the parasitic capacitors 14 to 17.

Thus, it can be said that, depending on the energy flow on the primary side of the transformer 18, a corresponding adaptation of the dead time 42 is effected, so that a substantial increase in the degree of effectiveness of the inverter is achieved. There is no longer just an adaptation of the pulse width, but the switching times for the switching elements 6 to 9 are optimized accordingly. What is essential, thus, is that the switching time, in particular the dead time 42, for switching over from one switching element 6 to 9 to a further switching element 6 to 9 connected in series, of the bridge inverter 5, is set by the connected d.c. voltage source 2 as a function of the energy produced. In doing so, the energy produced by the d.c. voltage source 2 is detected in particular at cyclical inter-

vals, and the switching time, in particular the dead time 42, is established, or determined, respectively, in accordance with the energy detected.

To achieve a further improvement in the degree of effectiveness of a solar system, a further possible way for an adaptation to the input performance of the solar inverter 1 is illustrated in the exemplary embodiment according to Fig. 3 described hereinafter. Again, the individual diagrams 28 to 33 are illustrated, as already shown in Fig. 2.

In this exemplary embodiment, an adaptation of the frequency or period duration 55, respectively, for the pulse width modulation is carried out in addition to the adaptation of the dead time 42 according to Fig. 2. Depending on the input performance prevailing, the period duration 55, or the switching frequency, respectively, for the switching elements 6 to 9 is changed, as is the case with the dead time 42. It is, of course, also possible for the solar inverter 1 to be constructed such that there will be only a change in the dead time 42 as a function of the energy delivered, or only a change of the period duration 55, or frequency, respectively, as a function of the energy delivered. Moreover, also a setting option may be provided, where

the user may choose between changing the dead time 42,
and changing the period duration 55, or frequency, re-
spectively, or may elect both options.

With an appropriate input energy, in the exemplary
embodiment according to Fig. 3 illustrated, the solar
inverter 1, in particular the bridge inverter 5, works
with a fixed period duration 55, or frequency, respec-
tively. If the input energy changes, i.e. if the former
is increased or reduced, this will be recognized by the
control device 24, whereupon a corresponding change of
the period duration 55, or frequency, respectively,
will be effected. This is shown at the point of time
56, at which an increase in the input energy occurs, as
is apparent from the current course I_{tr} according to
diagram 33. Thus, a new period duration 55, or fre-
quency, as well as a new dead time 42 is calculated, or
set, respectively, by the control device 24, and used
in the next switching-over period.

Setting of the new period duration 55, or fre-
quency, respectively, may be effected as described be-
fore in Fig. 2, i.e. the energy delivered by the d.c.
voltage source 2 is detected so that a corresponding
evaluation of the energy delivered will be enabled by
the control device 24 of the solar inverter 1 and,

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thus, the period duration 55, or frequency, respec-
tively, and/or the switching times, in particular the
dead time 42, will be set automatically by this control
device. Setting of the dead time 42 and/or of the pe-
riod duration 55, or frequency, respectively, may, how-
ever, also be effected by a calculation or by appropri-
ately stored data, i.e. by a table in which, e.g., pe-
riod durations 55, or frequencies, respectively, and/or
dead times 42 are stored which are related to the most
varying mean values. In this respect, setting of the
dead time 42 and/or of the period duration 55, or fre-
quency, respectively, occurs, for instance, on the ba-
sis of the mean value of the current flow I_{tr} through
the primary winding 19 of the transformer 18. Yet, it
is also possible for the energy flow to be constantly
monitored and for the control device 24 to react at a
change of the energy flow, whereby a new dead time 42
and/or period duration 55, or frequency, respectively,
is set.

The advantage of adapting the period duration 55,
or frequency, respectively, to the energy delivered re-
sides in that always the entire pulse width can be
utilized and, thus, an optimum operation will be en-
sured and, by this, the frequency-dependent switching

losses will be reduced. By the combination with the change of the dead time 42, it is also ensured that always the entire parasitic capacities can be recharged, without the possibility of high switching losses occurring, or of excessively long switching pauses for energy transmission being prevented.

It is also possible for a special switch-over procedure to be carried out for changing the dead time 42 and/or the period duration 55, or frequency, respectively. In this respect, it would be possible to run the final switching period, e.g., and subsequently to provide a short switching pause for the bridge inverter 5, whereupon, when the bridge inverter 5 is activated again, the new period duration 55, or frequency, respectively, and/or dead time 42 will be used. This would have the advantage that by this always a certain starting procedure, in particular a certain defined switching procedure, will be obtained with the same switching elements 6 to 9.